REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	11/19/96	Final Technical 2/1/93 - 8/31/96

4. TITLE AND SUBTITLE
Visual Perception of 3-Dimensional Form from Different Types of Optical Deformations

5. FUNDING NUMBERS
G-F49620-93-1-0116
61102F
2313/BS

6. AUTHOR(S)
James T. Todd

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Ohio State University, Department of Psychology
1885 Neil Avenue
Columbus, Ohio 43210-1222

8. PERFORMING ORGANIZATION REPORT NUMBER
AFOSR-TR-96
0573

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NL
110 Duncan Avenue, Suite B115
Bolling AFB 20332-8080

Dr John F. Tangney

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The research performed by James Todd during the past three years of AFOSR support has examined the abilities of human observers to determine an object's 3-dimensional form from various types of optical information such as shading, texture, motion or binocular disparity, both individually and in combination. The results of this research provide strong evidence that our perceptual representations of 3D metrical properties are surprisingly inaccurate and imprecise, but that observers are quite good at judging ordinal or nominal relations among different surface regions. We have also examined how these judgments are influenced by combinfing different types of optical information using both computer simulations and direct viewing of natural scenes.

19961206 189

14. SUBJECT TERMS

15. NUMBER OF PAGES
7

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
(U)	(U)	(U)	(U)

21 NOV 1996

Visual Perception of 3-Dimensional Form from Different Types of Optical Deformations

#F49620-93-1-0116

Final Technical Report: Feb. 1, 1993 - Aug. 31, 1996

The research performed in my laboratory during the past three years under AFOSR support has been designed to investigate the fundamental mechanisms involved in the perceptual analysis of 3-dimensional form and motion. Much of this research has been specifically motivated from a computational perspective. Our basic research strategy has been to identify the key assumptions of various competing models, and to empirically investigate the relative psychological validity of those assumptions using appropriate psychophysical procedures.

There are several different properties of optical structure from which observers are able to obtain information about the structure of the environment. We have tried in our research to consider a broad spectrum of issues involving the analysis and integration of these different sources of information, and to identify any common mechanisms or strategies that may be involved in multiple domains of perceptual processing. A brief summary of these ongoing programs is provided below.

The Detection of Motion

One line of research performed in my laboratory has been designed to investigate the competitive and coorperative interactions involved in the detection of coherent motion. For example, Norman, Norman, Todd & Lindsey (in press) have examined how perceived speed in one region of a display is influenced by the patterns of motion in neighboring regions, while Lindsey and Todd (1996) have investigated the role of luminance constraints on the perceived coherence of moving plaids.

A related series of experiments by Todd & Norman (1995) and Lindsey & Todd (submitted) has examined how processes of spatiotemporal integration can be used to filter spurious correlations (i.e., false targets) that can arise from the motions of densely textured patterns. In these studies we measured the maximum displacement and signal-to-noise thresholds for moving patterns that varied in size, shape, duration and eccentricity, and contained variable amounts of uncorrelated noise. The results indicate that the human visual system may have multiple mechanisms of noise filtering to facilitate the detection of coherent motion, including averaging over space and correlations of features or motions over multiple time intervals.

Perceived Structure from Motion

Another line of research we have been pursuing for several years involves the ability of observers to determine an object's 3D structure from its pattern of projected motion. There have been numerous theoretical analyses to prove that a complete euclidean reconstruction of an object under orthographic projection requires a minimum of three distinct views, but the empirical evidence suggests that human observers may only be sensitive to the first order spatiotemporal relations between pairs of views. The theoretical consequence of this limitation is that 3D structure from motion would only be specified up to a 1-parameter family of possible interpretations. In addition, observers would be unable to detect certain types of nonrigid distortions of an object that are invisible to 2-view analyses, but which could easily be detected

by more traditional algorithms for computing Euclidean metric structure. In our most recent investigations we have developed a variety of paradigms for testing these predictions (see Norman & Todd, 1993; Perotti, Todd, Lappin & Phillips, 1995; Perotti, Todd & Norman, 1996, Perotti, Todd, Lappin & Phillips, submitted), and the results confirm that observers' perceptions are primarily determined by first order spatiotemporal relations.

A fundamental assumption for most computational models of the perception of structure from motion is that multiple views of an identifiable image feature must all correspond to the same physical point in 3-dimensional space. There are numerous situations encountered in natural vision, however, for which this assumption is violated. Consider, for example, how an object's motion influences patterns of image shading, smooth occlusions, cast shadows or specular highlights. Because the optical contours produced by these phenomenon do not remain projectively attached to fixed locations on an object's surface, the changes produced by motion would be interpreted by most existing models as nonrigid distortions of 3D structure.

There is a growing amount of evidence to suggest, however, that is not how they are interpreted by the human visual system. Todd & Norman (1994) have shown that observers can identify nonrigid deformations from shadows and occlusion contours just as well as they are able to detect the nonrigid deformations of textured surfaces with identifiable features. This result has also been replicated by Norman, Todd & Phillips (1995) and Koenderink, van Doorn, Todd, Norman & Phillips (1996) using judgments of local depth and orientation for smoothly curved surfaces defined by the optical deformations of texture, shading, highlights and occlusion boundaries. We are currently trying to model how these other types of optical deformations could be perceptually analyzed to determine an object's 3-dimensional form.

The Perception of Metric Structure

A fundamental prerequisite for any computational analysis of 3D form perception is to define how an object's structure is perceptually represented. Although most existing computational models are designed to obtain a veridical interpretation of an object's Euclidean metric structure, there have been a few recent departures from this approach that have concentrated instead on more qualitative aspects of 3D form. Much of the evidence from our laboratory during the past several years has indicated that this latter approach is more representative of the perceptual processes performed by actual human observers.

One technique we have adopted to address this issue involves measuring discrimination thresholds for various metrical properties of 3D structure. For example, Norman, Todd, Perotti & Tittle (1995) obtained Weber fractions of approximately 2% for length discriminations in the frontoparallel plane, but these thresholds increased to over 25% when lines were presented in arbitrary 3D orientations as defined by motion and stereo. We have also obtained similarly high Weber fractions for discrimination of depth and orientation intervals on smoothly curved surfaces defined by shading, texture motion and stereo (see Norman & Todd, 1995, 1996; Reichel, Todd & Yilmaz, 1995; Todd & Norman, 1995). We are currently planning to expand this program by measuring thresholds for interval and ordinal relations for a wide variety of different surface properties (e.g., depth, slant, tilt, curvedness, etc.) that could potentially form the primitive units of our perceptual representations of 3D form.

In addition to measuring the precision of observers' judgments using discrimination paradigms, we have also performed numerous experiments to measure any systematic distortions that may exist in the perception of 3D structure (see Tittle, Todd, Perotti & Norman, 1995; Todd, Tittle & Norman, 1995; Koenderink, Kappers, Todd, Norman & Phillips, in press; Norman, Todd, Perotti & Tittle, in press; Todd, Koenderink, van Doorn & Kappers, 1996). We have employed several different paradigms for this purpose using both real objects and computer

generated displays as stimuli. The general pattern of results in all of these studies is that perceived intervals in depth tend to be systematically expanded or compressed relative to those in the frontoparallel plane. The precise magnitude of this depth scaling is influenced by a variety of different factors, which we have only just begun to explore.

One important factor that can influence the pattern of perceptual distortion is the particular combination of optical properties by which an object's structure is perceptually specified (e.g., shading, texture, motion and/or binocular disparity). In many of our experiments we have systematically manipulated the available sources of information by presenting them in all possible factorial combinations (see Norman, Todd & Phillips, 1995; Tittle, Todd, Perotti & Norman, 1995; Todd, Koenderink, van Doorn & Kappers, in press). We have also obtained observers' judgments of perceived structure for displays in which the available sources of information are in conflict with one another (see Norman & Todd, 1995; Tittle, Perotti & Phillips, 1995; Tittle, Perotti & Norman, in press). The results of these studies indicate that motion and stereo are the dominant sources of optical information, and that their relative weights can vary significantly depending upon the specific aspect of 3D structure an observer is asked to judge.

The Perception of Nonmetric Structure

Although the perception of 3D metrical structure can be highly distorted and imprecise, observers are typically quite good at judging ordinal or nominal relations. In one recent experiment, for example, we compared performance for two different aspects of perceived relative depth on smoothly curved surfaces defined by shading, texture, motion and stereo. For depth interval discriminations, we obtained Weber fractions of approximately 25%. For depth order discriminations, in contrast, the Weber fractions were reduced to less than 1%. Such findings indicate that observers may have a very accurate perceptual representation of the depth order relation between two points without necessarily knowing the precise magnitude of their separation in depth.

We have also performed a number of recent experiments on the identity relation between multiple views of an individual surface point when it is observed from different orientations (see Koenderink, van Doorn, Kappers & Todd, in press; Phillips, Todd, Koenderink & Kappers, in press). The paradigm we have developed for investigating this property is conceptually quite simple. Observers are presented with a pair of objects that are structurally identical, except that they have different random textures and are positioned at different orientations in depth. A single point on one of the objects is highlighted with a small colored dot, and the observer's task is to identify the corresponding point at a different orientation on the second object. For orientation differences up to 30 degrees, the average errors within the object's projected image are typically no larger than a few minutes of arc! We are currently planning an additional series of experiments in an effort to reveal how the view-point invariant identity of a point is perceptually determined from various aspects of optical information.

Published Manuscripts

Norman, J.F., & Todd, J.T. (1993) The Perceptual analysis of structure from motion for rotating objects undergoing affine stretching transformations. Perception & Psychophysics, 53, 279-291.

Todd, J.T. (1994) On the optic sphere theory and the nature of visual information. In G. Jansson, S. S. Bergstrom & W. Epstein (Eds.), Perceiving events and objects. Hillsdale, NJ: Erlbaum, pp 471-478.

Norman, J. F. & Todd, J. T. (1994) The Perception of rigid motion in depth from the optical deformations of shadows and occlusion boundaries. Journal of Experimental Psychology: Human Perception and Performance, 20, 343-356.

Todd, J. T., Tittle, J. S., & Norman, J. F. (1995) Distortions of 3-dimensional space in the perceptual analysis of motion and stereo. Perception, 24, 75-87.

Norman, J. F., Todd, J. T., & Phillips, F. (1995) The perception of surface orientation from multiple sources of optical information. Perception & Psychophysics, 57, 629-636.

Norman, J. F., & Todd, J. T. (1995) Perception of 3-dimensional structure from contradictory optical patterns. Perception & Psychophysics, 57, 826-834.

Tittle, J. S., Todd, J. T., Perotti, V. J., & Norman, J. F. (1995) The systematic distortion of perceived 3D structure from motion and binocular stereopsis. Journal of Experimental Psychology: Human Perception and Performance, 21, 663-678.

Todd, J. T. (1995) Information for spatial layout in dynamic optical stimulation. In W. Epstein & S. J. Rogers (Eds.) Handbook of perception and cognition, Volume 5: Perception of space and motion. Orlando, FL: Academic Press. pp. 201-226.

Tittle, J. S., & Todd, J. T. (1995) The perception of three-dimensional structure. In M. A. Arbib (Ed.) The handbook of brain theory and neural networks. Cambridge, MA: MIT Press. pp. 715-718.

Todd, J. T. & Norman, J. F. (1995) The effects of spatio-temporal integration on maximum displacement thresholds in the detection of coherent motion, Vision Research, 35, 2287-2302.

Reichel, F. D., Todd, J.T., Yilmaz, E., (1995) Visual discrimination of local surface depth and orientation. Perception & Psychophysics, 57, 1233-1240.

Todd, J. T., & Norman, J. F. (1995) The visual discrimination of 3D angles. Perception, 24, 855-866.

Lindsey, D. T. & Todd, J. T. (1996) The perception of transparency in moving plaids. Vision Research, 36, 207-222.

Norman, J. F., Todd, J. T., Perotti, V. J. & Tittle, J. S. (1996) The visual perception of 3D length. Journal of Experimental Psychology: Human Perception and Performance, 22, 173-186.

Todd, J. T., Koenderink, J. J., van Doorn, A. J., & Kappers, A. M. L. (1996) Effects of changing viewing conditions on the perceived structure of smoothly curved surfaces. Journal of Experimental Psychology: Human Perception and Performance, 22, 695-706.

Perotti, V. J., Todd, J. T. & Norman, J. F. (1996) The visual perception of rigid motion from constant flow fields. Perception & Psychophysics, 58, 666-679.

Todd, J. T. (1996) The visual perception of 3D shape. In A. M. L. Kappers, C. J. Overbeeke, G. F. F. Smets, and P. J. Stappers (Eds.) Studies in ecological psychology. Delft, The Netherlands: Delft University Press. pp. 89-102

Norman, J. F. & Todd, J. T. (1996) The discriminability of local surface structure. Perception, 25, 381-398.

Phillips, F., & Todd, J. T. (1996) The visual perception of local shape. Journal of Experimental Psychology: Human Perception and Performance, 22, 930-944.

Koenderink, J. J., Kappers, A. M. L., Todd, J. T., Norman, J. F. & Phillips, F. (1996) Surface and attitude probing in stereoscopically presented dynamic scenes. Journal of Experimental Psychology: Human Perception and Performance, 22, 869-878.

Norman, H. F., Norman, J. F., Todd, J. T., & Lindsey, D. T. (1996) Spatial interactions in perceived speed. Perception, 25, 815-831.

Todd, J. T. (1996) Theoretical and Biological Limitations on the visual perception of 3D structure from motion. In T. Watanabe (Ed.) Higher-level motion processing: An interdisciplinary approach, North Holland Press.

Phillips, F., Todd, J. T., Koenderink, J. J. & Kappers, A. M. L. (1997) The Identification of features on smoothly curved surfaces? Journal of Experimental Psychology: Human Perception and Performance, in press.

Koenderink, J. J., van Doorn, A. J., Kappers, A. M. L. & Todd, J. T. (1997) The Visual contour in depth. Perception & Psychophysics, in press.

Tittle, J. S. Perotti, V. J. & Norman, J. F. (1997) The integration of binocular stereopsis and structure-from-motion in the discrimination of noisy surfaces. Journal of Experimental Psychology: Human Perception and Performance, in press.

Perotti, V. J., Todd, J. T., Lappin, J. S. & Phillips, F. (1997) The perception of surface curvature from optical motion. Perception & Psychophysics, in press.

Lindsey, D. T. & Todd, J. T. (1997) Opponent interactions in the perception of transparent motion. Perception & Psychophysics, submitted.

Todd, J. T., Norman, J. F., Koenderink, J. J. & Kappers, A. M. L. (1997) Effects of texture, illumination and surface reflectance on stereoscopic shape perception. Perception, submitted

Norman, J. F. & Todd, J. T. (1997) The discrimination of interval and ordinal depth relations on smoothly curved surfaces. Perception, submitted.

Published Abstracts

Todd, J. T., Norman, J. F., Perotti, V. J., & Tittle, J. S. (1993) The discrimination of 3D length from motion and stereopsis. Investigative Ophthalmology & Visual Science, 34, 1131.

Tittle, J. S., Perotti, V. J., Todd, J. T., & Norman, J. S. (1993). The perception of relative surface orientation from binocular disparity and motion. Investigative Ophthalmology & Visual Science, 34, 1132.

Norman, J. F., & Todd, J. T. (1993) Directional anisotropies determine the perceived structure of contradictory motion and binocular disparity fields. Investigative Ophthalmology & Visual Science, 34, 1082.

Ruda, H., & Todd, J. T., (1993) Effects of area and target separation on vernier acuity for stimuli defined by luminance, texture and motion. Investigative Ophthalmology & Visual Science, 34, 1029.

Norman, J. F., Todd, J.T., & Phillips, F. (1993). The visual perception of surface orientation. Bulletin of the Psychonomic Society, 31, 358.

Todd, J.T., Perotti, V. J. & Norman, J. F. (1993). Perceived rigid rotation in depth from constant flow fields. Bulletin of the Psychonomic Society, 31, 378-379.

Norman, H. F., Todd, J. T., & Lindsey, D. T. (1994) Spatial interactions in perceived velocity. Investigative Ophthalmology & Visual Science, 35, 1271.

Perotti, V. J. & Todd, J. T., Tittle, J. S., & Norman, J. F. (1994) Perception of 3D form from instantaneous flow components. Investigative Ophthalmology & Visual Science, 35, 1317.

Todd, J. T. & Norman, J. F. (1994) The visual perception of 3D length in natural vision. Investigative Ophthalmology & Visual Science, 35, 1329.

Lindsey, D. T. & Todd, J. T. (1994) Opponent motion interactions in transparent motion. Investigative Ophthalmology & Visual Science, 35, 1389.

Kappers, A. M. L., Koenderink, J. J., Todd, J. T., & Norman, J. F. (1994) Depth and attitude probing in dynamic scenes. Investigative Ophthalmology & Visual Science, 35, 1626.

Phillips, T. F., Todd, J. T. & Norman, J.F. (1994) The perception of local 3D shape. Investigative Ophthalmology & Visual Science, 35, 1627.

Norman, J. F., Todd, J. T., Phillips, F. (1994) Perception of 3D structure from multiple sources of optical information. Investigative Ophthalmology & Visual Science, 35, 1742.

Perotti, V. J. & Todd, J. T., Lappin, J. F. & Phillips, F. (1995) Perceived shape index and curvedness from constant flow fields. Investigative Ophthalmology & Visual Science, 36, 361.

Phillips, F., Todd, J. T., Koenderink, J. J., & Kappers, A. M. L. (1995) What defines features on smoothly curved surfaces. Investigative Ophthalmology & Visual Science, 36, 847.

Tittle, J. S., Perotti, V. J. & Phillips, F. (1995) The integration of surface shape and curvedness from motion and binocular stereopsis. Investigative Ophthalmology & Visual Science, 36, 847.

Norman, J. F., & Todd, J. T. (1995) The discriminability of metrical and nonmetrical properties on smoothly curved surfaces. Investigative Ophthalmology & Visual Science, 36, 1068.

Lindsey, D. T. & Todd, J. T. (1995) The detection of motion in transparent motion displays. Investigative Ophthalmology & Visual Science, 36, 1048.

Todd, J. T., Norman, J. F., Koenderink, J. J., & Kappers, A. M. L. (1996) Effects of texture, illumination and surface reflectance on stereoscopic shape perception. Investigative Ophthalmology & Visual Science, 37, 1934.

Norman, H. F., Norman, J. F., & Todd, J. T. (1996) Spatial interactions in perceived speed. Investigative Ophthalmology & Visual Science, 37, 744.